Taking a bold action to develop dynamic earthquake simulators in next earthquake research center(s)

Dr. Benchun Duan
(*Department of Geology & Geophysics, Texas A&M University)*

As the coronavirus epidemic is rapidly evolving in the US and across the world at the start of this writing (March 31, 2020), modelers and modeling have been playing an increasingly important role in assessing what will happen with different strategies/scenarios and thus in the government's decision-making as demonstrated in recent presidential press briefings. In preparing for possible damaging earthquakes along the west coast of the US, including those that will occur on the San Andreas Fault (SAF) system or the Cascadia Subduction Zone (CSZ), the earthquake science community need to take a bold action to develop dynamic earthquake simulators that can capture both the quasi-static deformation processes and the co-seismic dynamic process of earthquake cycles on large-scale, realistically complex fault systems. (An) earthquake research center(s) can make this goal to be feasible with dedicated researchers, coordinated efforts, and stable funds.

What are they and how they are different from well-known earthquake simulators in the community? Basically, dynamic earthquake simulators are earthquake simulators that include spontaneously dynamic rupture propagation, besides other quasi-static deformation processes of earthquake cycles. Actually, a prototype of dynamic earthquake simulators exists in the community, i.e., the one developed and used by Dr. Lapusta [e.g., Lapusta et al., 2000; Lapusta and Liu, 2009] at Caltech and her colleagues for a decade. However, their earthquake simulator appears to be limited to a single vertical, planar strike-slip fault. Also, it seems also being limited to a homogeneous medium. These limitations prevents it from being able to apply to realistically complex fault systems with heterogeneous geological structure. On the other hand, some well-known earthquake simulators, such as RSQsim pioneered by Dr. Dieterich and improved and used by him and his colleagues [e.g., Dieterich and Richards-Dinger, 2010], can be applied to realistically complex fault systems such as the SAF and CSZ and produce earthquake sequences that mimic observations statistically. However, these earthquake simulators do not simulate the spontaneously dynamic rupture propagation process, which is very critical for assessing multi-fault ruptures.

A vision for dynamic earthquake simulators: I envision these dynamic earthquake simulators will be able to bridge gaps between different modeling communities, at least including those who focus on the quasi-static deformation processes that are constrained by geodetic and geologic observations between earthquakes and those who focus on the dynamic rupture process that can be constrained by seismic, geodetic, and geologic observations of large earthquakes. They can assimilate seismic, geologic, and geodetic observations through earthquake cycles, and thus can be used as tools to extract more information about earthquake generation processes from increasingly abundant observations, and to form more and better/improved hypotheses about earthquake physics. They can also be used to simulate/predict ground motions for target areas from future scenario earthquakes with dynamic source and heterogenous geologic structure. They may also be used as fundamental tools for physics-based earthquake forecast and prediction.

Feasibility and complementary to other closely related efforts: My group has been working on developing these dynamic earthquake simulators [Liu et al., 2020; Luo et al., 2020]. We exploit two schemes. In Liu et al. [2020], we develop a quasi-static finite element method (FEM) code to model the quasi-static processes (including interseismic, nucleation, and postseismic) and integrate it with our existing dynamic FEM code EQdyna for spontaneous rupture. In Luo et al. [2020], we simulate earthquake cycles based on EQdyna, with a dynamic relaxation (DR) technique for modeling the quasi-static processes with the dynamic solver (EQdyna), and thus earthquake cycles can be simulated within one FEM framework. These initial efforts show that developing these dynamic earthquake simulators is feasible, though much more efforts are needed to achieve the above vision with these simulators, including, but not limited to, 1) parallelizing and scaling them to make use of ever increasing HPC (high-Performance Computing) powers for real fault systems, 2) developing and testing mechanically robust schemes to load the fault systems, and 3) incorporating more physical processes that likely operate during earthquake generation processes, such as hydro- and thermal-processes and rock damages. These efforts will make the models as good as they can be and to be applicable in real seismic hazard analyses and forecast, such as ground motion prediction with dynamic source and physics-based earthquake forecast, even exploring physical controls on induced seismicity. There are other efforts in the community, advocated by other colleagues, which specifically focus on some earthquake source processes (such as fluid effects on earthquake processes) and do not attempt to integrate all (or most) physics into one model for simplification and/or other causes such as deeper understanding of some physical processes and/or avoiding computational demands. These efforts will be complementary to what I propose here, and I do not think the community should be dominated by these efforts and intentionally disregard what I propose here. There is no doubt what I propose and envision are ambitious and very challenging, but they should be one important direction/effort pursued by the community and supported by funding agencies.

What we need and how earthquake research center(s) can facilitate: We need a community effort to develop these dynamic earthquake simulators and use them for earthquake physics studies and seismic hazard analyses. Different groups with experience in quasi-static deformation modeling or spontaneous rupture modeling can work together to incorporate what we know and/or what we hypothesize about physical processes into these models. Seismologists, geologists and geodesists can help constrain these models with corresponding observations (data) and can use these models to extract more information from these observations. Earthquake research center(s), such as SCEC, will significantly facilitate these collaborations. I envision one large earthquake research center or two intermediate-size earthquake research centers. One focuses on complex strike-slip fault systems such as the SAF, and the other focuses on subduction zone processes such as along the CSZ. One large center can include both aspects with more challenges in management.

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